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AN EXTENSION OF THE KNOWN AREA OF PLEISTOCENE GLACIATION TO THE COAST RANGES OF CALIFORNIA

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By recent usage the application of the term, Coast Ranges of California, is limited to the series of roughly parallel ridges lying west of the great central valley of the state and extending from the Klamath Mountains on the northwest to the Mt. Pinos group situated southward of the extreme upper end of the San Joaquin valley. This complex of mountains around Mt. Pinos may be considered as formed by the meeting of the Coast Ranges, the Sierra Nevada, and the Sierra Madre of southern California. Without further qualification the term Coast Ranges will be used in this restricted sense in the following paper.

On maps showing the extent of Pleistocene glaciation in North America, the only portions of California commonly included are Mt. Shasta and the higher slopes of the Sierra Nevada. During the past ten years, largely through the work of Diller* and of Hershey,† it has become known that the Klamath mountains were rather extensively glaciated and that the lower limit of the ice was probably below that in the Northern Sierra. This region is shown on a map in the third volume of Chamberlain and Salisbury's "Geology" and since the publication of that work, Fairbanks and Carey‡ have added an area in Southern California by finding indications of glaciation in the San Bernardino Mountains. But hitherto it has been tacitly

Bull. 196, U. S. G. S., p. 58. †*Jour. Geol.* VIII, 1900, p. 42. ‡*Science*, 31, 1910, p. 32.

assumed that the Coast Ranges never have been subject to glaciation. This assumption has been made, apparently on the ground of their lesser elevation compared to the Sierra Nevada and without due consideration of other factors than elevation as causes of local glaciation. In studying the physiography of California, the writer has been impressed with the relatively heavy precipitation in the mountains of the Coast Province and also with the unappreciated height of many of the ranges. The further fact that the higher mountain tops in these regions at present carry snow until late in summer led to a determination to make a search for evidences of local glaciation.

The range selected for the first exploration forms the steep western rim of the upper Sacramento valley. It extends approximately north and south for about one hundred miles and the character of its topography is shown by the fact that although the country to the west is quite well settled and although the great agricultural plain of the Sacramento is on the east, there is as yet no wagon road crossing the range. The main ridge is reported as being quite uniform in height throughout the greater portion of its extent. Only two peaks have been definitely measured, Snow Mountain near the southern end being 7,039 feet in elevation (U. S. C. G. S.), and Mt. Linn near the northern end being 8,604 feet (U. S. G. S.). Hunters and sheep herders report that portions of the ridge to the southward of Snow Mountain surpass it in elevation. A map recently published at Sacramento gives one of the peaks, Mt. Ripley, as 7,500 feet without, however, quoting any authority. Snow Mountain was visited in 1909, and again, with a camera, in the past summer. Four or five square miles on the northern and eastern slopes of the peak were found to bear clearest evidences of glaciation, as will be described in detail below. The northern part merges into the Klamath Mountains, and connects with the glaciated area described by Diller and Hershey. Snow Mountain, a slightly elevated portion of the main ridge, is situated northeast of Clear Lake on the eastern boundary of Lake County. The Coast Survey monument at the top marks also the southwest corner of Glenn County, and the northwest of Colusa. Fout Springs at the eastern foot of the mountain is the most convenient base for exploring the peak. The hotel at the Springs is accessible by wagon road from Sites or from Willows.

From Fout Springs a private road leads northward up the slope of the mountain to the Caldwell ranch, at an elevation of about 2,850 feet. Thence a steep but well-marked trail leads westward over the ridge between the peaks of Snow Mountain. Distinct signs of glaciation are first seen about two miles from the summit at

5,950 feet elevation (aneroid). Here the trail crosses a terminal moraine which lies at the mouth of a hanging valley (A of the sketch model) that opens northward into the sharply incised gorge of one of the branches of Stony Creek, the main drainage channel of the region. (Fig. 1.) The moraine lies partly against a low elliptical hill which extends in the direction of the main valley. The rounded outline of this hill indicates that it was probably over-ridden by the ice. The moraine is rather closely overgrown with brush, but there are several exposures of unstratified detrital material, the fragments vary-

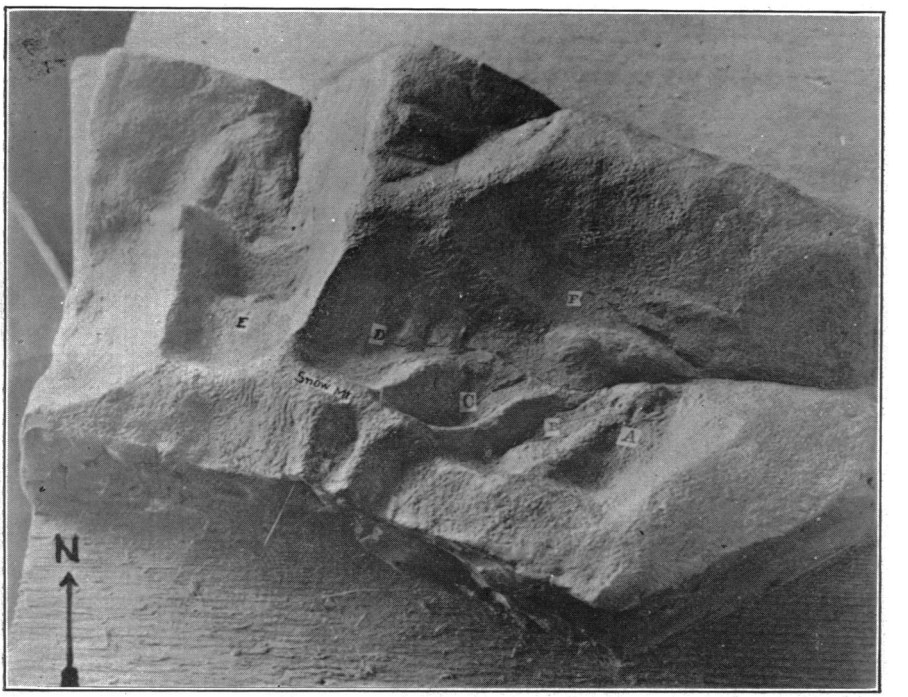

FIG. 1—Model of Snow Mountain, showing glaciated valleys.

ing greatly in size. The surface of the moraine is very uneven, one of the larger depressions being some 300 feet in length and about 25 feet deep. Just above the moraine at its east end is a small meadow not yet fully drained by the channel which is being cut by the overflow in the rainy season. The U-shaped valley above the meadow, heads against the main ridge of Snow Mountain without subdivision into water-cut gorges and ravines and also without the steep cirque walls so common in the granite in similar valleys in the Sierra.

The main rock of Snow Mountain in the area studied is diabasic

and weathers rapidly giving extensive talus slopes that mask all cliffs not swept by active streams. The weathering is so rapid and wide-spread that it required considerable search to obtain a specimen sufficiently unaltered to show fairly the character of the rock. Glacial markings would not usually be preserved in such rock except where it was protected from the weather. Definite glacial striæ were found in this valley, only at the eastern end of the elliptical hill already mentioned.

Going westward toward the main pass, other tributary valleys, B and C, have the same northward exposure and general characteristics as A, but lack definite terminal moraines. They are larger and their glaciers apparently merged into the glacier of the main valley. The third valley, C, has steeper cirque-like walls and its floor affords several examples of well-preserved glacial striæ with the bearings approximately parallel to each other and to the axis of the valley. The photograph reproduced in Fig. 2 is from this valley and is a fair representation of the definiteness of the striæ found in some fifteen to twenty of the best bed-rock exposures. Angular fragments with one or more faces striated were not wanting in the drift, but the striæ found on bedrock make it unnecessary to consider them as part of the evidence of glaciation. This is fortunate in a much-faulted region like the Coast Ranges, where the scratches on "slickensided" surfaces closely simulate glacial striæ. The ridge between B and C is over 100 feet in height and striæ on top show that it was covered by the ice. At D the main valley floor rises in steps of 100 and 150 feet, and the valley ends in a well-rounded head. The walls are covered with talus almost to the top, with a somewhat indefinite bench in several places at a rather uniform level over 200 feet below the top of the ridge.

Crossing the main divide of the northwest slope of the mountain, the best developed form of glacial valley was found in F, which extends nearly two miles northward before its flat floor is cut by stream erosion, into the steep gorge characteristic of the slopes below the 6,000 feet contour. The steep walls at the head of this valley inclose a little meadow, that is a duplicate of many of the smaller glacial meadows of the High Sierra. Some distance below, the valley floor descends abruptly some 200 to 300 feet to a second meadow, again duplicating characteristic Sierra forms in this step-like succession of basins. The sharp ridge to the west of this valley ends near the second meadow in the most precipitous cliff found, and from near its base runs a well-defined moraine some 25 feet in height. This is evidently the lateral moraine of valley F augmented by material from

a small tributary glacier coming down from the westward. The rock exposures in this valley show much weathering, and despite the surprisingly striking glacial forms shown in the topography, no striæ were found in the brief time given to examination.

Recrossing the divide, the north fork of the main valley, E of the sketch model, has the largest meadow of all and also some well-preserved roches-moutonnées with striæ at the base, very distinct, but too small to show well in the photograph. (Fig. 3.)

Glacial striæ are found on bedrock in several places in this valley

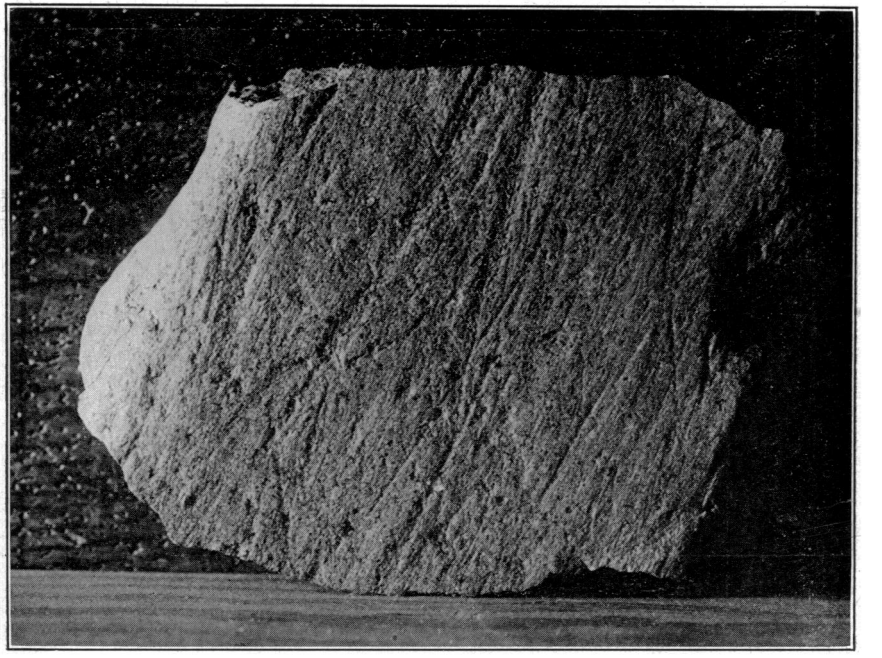

FIG. 2—Striæ found on bed rock in glaciated valley of Snow Mt.

and lateral moraines on both sides, the most definite being on the north slope of the lower part of the valley.

This slope is well wooded and difficult to photograph, but in the field the boulders and unstratified material of the moraine and its uneven surface are in striking contrast to the smooth talus of the main valley with its uniform and rather fine fragmental material.

Owing to lack of time and the difficulty of working in a region entirely without reliable maps, no attempt was made to fix the limits of the glaciated area in this portion of the range. The work done,

however, shows clearly the fact of glaciation and that the lower hypsometric limit is below the 6,000 feet contour.

Some consideration will now be given to the general topography and the climatic conditions and to a brief comparison with the glaciated portion of the Sierra Nevada lying in the same latitude. The remarkably flat top of the main ridge (see Fig. 4), and the rather mature topography for a mile or two of the higher slope on either side, mature where not rejuvenated by glacial erosion, all suggest that the mountain forms part of an uplifted oldland. In fact, Diller* merely from a distant view, has already described Snow Mountain

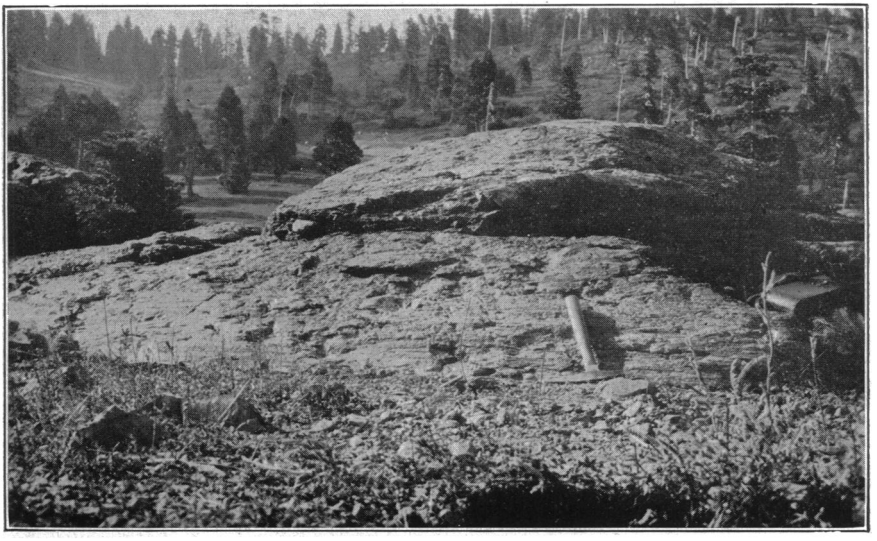

FIG. 3—Well-preserved Roches-Moutonnées in Valley F., Snow Mt.

and St. John, a nearby peak, as "rising but little above the flat portion of the Klamath peneplain."

This remnant of an old peneplain forming the summit of this portion of Snow Mountain range constituted the névé field in glacial times. Wherever by headward erosion the streams of the newer cycle initiated by the last great uplift had reduced this flat top to a narrow ridge it is impossible that any glaciers were formed.

The extremely youthful gorges of the middle slope of the mountain are rapidly working their way headward into the upper valleys and it will be very difficult if not impossible to determine exactly the lowest extension of the ice in those valleys which were glaciated.

* Bulletin 196, U. S. G. S., p. 20.

Of the upper valleys seen from the main ridge, beside those described above, the majority showed from a distance no sign of glaciation, but one or two had the U shape and the rounded heads suggestive of possible ice action. The local causes determining glaciation in these different valleys were probably exposure, relation to the snow-drifting winds, and local precipitation, the latter probably varied greatly along the range with the adaptability of the valleys on the western slope to the creation of a strong local up-draft of the moisture bearing storm winds. Some forty miles to the southward, near the summit of the next main ridge of the Coast Ranges, is a station that frequently reports to the Weather Bureau an annual precipitation of from 100 to 130 inches in a region where the surrounding stations report about one half that amount. While the cause of the heavy

FIG. 4—Flat top of the Main Ridge about one-half mile southeast of Snow Mt.

precipitation has not been carefully worked out, it appears that it is probably due to a rather steep valley opening to the winter storm winds in such a way as to act like an upward pouring funnel. The condensation in such up-pourings of nearly saturated air might well in Pleistocene times have determined a local glacier on a mountain range, the top of which was along the critical line marking the border of glaciation.

The latitude of the main peak of Snow Mountain is 39° 22′ N. Directly to the eastward in the Sierra Nevada is the glaciated region to the northward of Lake Tahoe. A comparison of the limits of glaciation and of the records of present precipitation in the two regions is of interest. As the crest of the Sierra at this latitude is some 2,000 feet higher than Snow Mountain, comparison should be made with some of the small glaciers of the ridges of the western Sierran slope. The Canyon Creek glacier heads among peaks vary-

ing from 7,000 to 8,000 feet in height and may be taken as equivalent as the parallel of 39° 25′ passes through its main valleys. The higher peaks are described as having projected above the surface of the glacier. According to the contour lines, the cirques must have headed at from 6,500 to 7,000 feet. The lower limit of the ice "is not established beyond doubt" but the morainal matter described about Graniteville indicates that it was at least as low as 5,500 feet. These upper and lower limits agree closely with those found at Snow Mountain. The present precipitation for the two regions seems also to be approximately equal.*

In the table below the few stations around Snow Mountain are compared with those of practically the same elevation and similar location in the Canyon Creek district. The figures are from the annual summary for 1909 of the California Section of the Climatological Service of the Weather Bureau:

	FEET.	INCHES.
Westward of Snow Mt.	Elevation.	Annual Precipitation.
North Lakeport.....	1,450	47.
Hullville.....	2,250	72.
Helen.....	2,750	136.
West of Canyon Cr.		
Dobbins.....	1,650	68.
Nevada City.....	2,580	76.
Bowmans Dam.....	5,500	113.

At Fout Springs, elevation 1,650 feet, at the eastern base of Snow Mountain and in the rain shadow of the range, the precipitation was over 60 inches for 1909, 30 inches falling in January. On Aug. 27 of the same year extensive snow banks were still to be found on Snow Mountain, although the *mean* temperature for June to September at Fout Springs, six miles distant was 67° F. with maxima for the same months varying from 91° to 98° F. The nearest corresponding station east of the Sierra for the Canyon Creek district is Boca, elevation 5,531 feet, where the yearly precipitation was but 37 inches.

It is, of course, recognized that so many local conditions affect the record of precipitation that the figures quoted above are merely suggestive. Their pertinence in studying the general question of Pleistocene glaciation lies in the fact that it is commonly accepted that topography was practically the same then as now and that there is no evidence of a change in our wind system. The Coast Ranges lie squarely athwart the prevailing west winds from the Pacific and, other things being equal, precipitation should be heavier at the same

* Colfax Folio, No. 66, U. S. G. S., p. 7.

elevations than in the Sierra to the eastward. The records for Snow Mountain and the Canyon Creek region show approximately equal precipitation for the same elevations and approximately the same mean temperature is indicated by the fact that at 7,000 feet snow lingers till late summer in both regions. That both regions were formerly glaciated suggests the working hypothesis that the higher portions of the Coast Ranges when situated in areas of relatively heavy precipitation were possibly subject to Pleistocene glaciation. The most promising fields for further study according to this hypothesis will now be briefly indicated.

If the reported heights of other portions of Snow Mountain are confirmed, glaciation may be found some fifteen to twenty miles southward of Snow Mountain. To the northward the higher peaks should show signs of ice action wherever they have sufficient area to have afforded gathering fields for snow. To the north of west from Snow Mountain and distant some twenty miles is Mt. San Hedrin, its rather broad flat summit rising to 6,183 feet. As rainfall increases rapidly in this direction it should be included in any comprehensive search. Southward through Central California the ranges decrease in height, Mt. Diablo nearly opposite the Golden Gate being but 3,849 feet in elevation. South of Monteray Bay the height increases again, Santa Lucia range having one peak, Santa Lucia West, that reaches to 6,000 feet. (U. S. C. G. S.) The rainfall maps of the State do not give this as an area of unusually heavy precipitation. It must be remembered, however, that the higher elevations in sparsely settled regions like this have practically no reliable data for rainfall maps. Still further southward the complex of mountains formed by the meeting of the three great mountain systems of the State is a region of relatively heavy precipitation. Several of the peaks are over 7,000 feet high and Mt. Pinos rises to 8,826 feet.

The nearest glaciated region which may be taken for comparison is the upper basin of the Kern River,* where Lawson has fixed the southern limit of glaciation at 36° 20′ (36° 16′ according to the Kaweah topographic sheet since issued). The elevation of the ridge against which head the small glacial cirques on the west side of the little Kern is about 10,000 feet, with the cirques themselves heading at from 9,000 to 9,500 feet. The rainfall maps for the higher parts of the Mt. Pinos group and for the Kern Basin region are necessarily generalized from rather distant stations. The Southern Sierra is, however, credited with the greater precipitation. In addition, the

* *Bull.* Dept. Geol., Univ. Cal., Vol. 3, Plate 31.

Kern region has the higher latitude, its southern boundary being 36° 16′ N. while Mt. Pinos is but 34° 57′ N.

The probability of finding evidences of former glaciation on Mt. Pinos would seem slight from this comparison, but the hearsay evidence concerning snow in late summer and peculiar topography is more encouraging than were similar reports from Snow Mountain. It certainly should be carefully studied, for it is very possible that the precipitation is greater than reported. It should also be noted that Mt. Pinos is on the border line of two of the climatic divisions of the State and that such a border zone may have had a proportionately greater rainfall during the climatic variations of the glacial period. Whoever undertakes to examine this region should remember that the San Andreas Rift, along the northern part of which motion occurred in the earthquake of 1906, passes only some three miles to the northward of the summit of Mt. Pinos. The irregularities of surface caused by landslides and other movements along a fault zone might be confusing in some relations to an observer predisposed to see morainal topography.

Résumé: Briefly summarizing the paper, it may be stated that clear evidence of glaciation exists on Snow Mountain; that a strong probability exists that other areas in the northern Coast Ranges were also glaciated; and that there is at least a possibility that some of the peaks of the southern Coast Ranges including the Mt. Pinos Group may have carried small Alpine or cliff glaciers.

GEOGRAPHIC INFLUENCES IN AMERICAN SLAVERY*

BY

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The Coastal Plain in Alabama and Mississippi, as in the other regions, is belted and largely covered with a veneer of Lafayette and Columbia sediments. The chief distinction between the Coastal Plain in the areas before considered and in the Western Cotton Belt is the occurrence of extensive limestone belts in the latter. (Fig. 18.) While the Lafayette and Columbia formations cover much of the Gulf Coastal Plain, they are absent or meagerly developed on the

*Concluded from *Bulletin* January and February, 1911.